3 Base Station Transceiver Performance Characterization

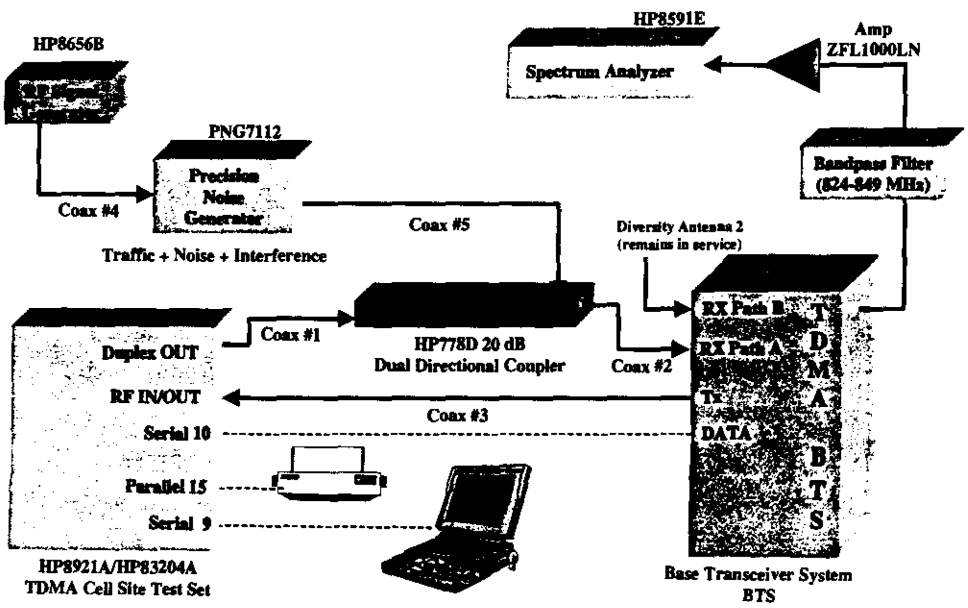
3.1 Receiver Bit Error Rate Test - Configuration

This test was a Cell Site BER characterization, in which a cell site transceiver (TRU) was fed a TDMA signal of interest, AMPS interference, and additive 'white' gaussian noise to simulate background noise in populated environments. The TDMA signal of interest was generated by an HP8921A test set with an HP83204A TDMA Adapter, loaded with modified HP11807B software designed to work with the Nortel TDMA base station.

The HP test set controlled the base station transceiver (TRU) via a direct serial data connection, and reported test results. An HP8656B signal generator modulated by an audio function generator provided the FM signal simulating an AMPS interferer. 'White' noise was supplied by a Noise/Com Precision Noise Generator, model PNG7112, which covers frequencies up to 2 GHz. The test instrumentation is shown in Figure 3.1.

The software modifications to the HP off-the-shelf product were minor, and affected two areas: First, an 'outside' loop was added to the software, easing the highly iterative testing, This loop incremented the TDMA signal level a fixed amount per measurement. The second modification bypassed the cable loss test (which required moving cables) at the beginning of a measurement, allowing entry of the cable loss information manually, once per run, which also provided better data consistency... The cable loss value was obtained from manual calibration prior to testing. *Some software changes were made by AirCell, and some later, in the field by WSE. To prevent any possibility that the modifications would have an accuracy-changing effect, SAFCO and WSE engineers verified in detail all changes, including a line by line comparison between the commercial release software and the modified software.* None of the changes were determined to affect measurement results.

Figure 3.1 – Cell Site Transceiver Characterization Setup



As this test setup utilized a hard-cabled connection of known loss between the signal sources and BTS, receive diversity was not needed for the test. Indeed, only one receiver input was selected by the HP test set software at a time. Thus, only one of the receive diversity paths was taken off line for testing; 'Path A', while the other radios at the site (those not under test) remained in service using diversity 'Path B' only.

In operation, the HP8921A Cell Site Test Set commanded the radio under test into a loopback mode to enable measurement of the reverse channel Bit Error Rate. The 8921 then generated a pseudo-random IS-136 compatible data digital signal and transmitted it to the Transmit Receive Unit (TRU) via the site receive multicoupler (Path A). The TRU translated the signal to the forward channel frequency and transmitted it back to the HP8921A Cell Site Test Set at a high power (>20 watts) via a cabled 'forward link' connection through which BER was negligible. Since the focus of the test was reverse link BER (which reverse channel AirCell transmissions could influence) it was appropriate to drive forward link BER to zero in order to remove what would otherwise be an uncontrolled experimental variable. The HP8921A Cell Site Test Set compared the transmitted pseudo-random digital signal to the received digital signal and calculated the (reverse link) BER.

3.2 Receiver Bit Error Rate Test Setup - Calibration

As there were several passive RF splitters, couplers, and cables in the test setup, a detailed calibration of path losses between (calibrated) signal sources and the site multicoupler input (the testing reference point) needed to be carried out. Proper amplitude referencing was critical to the accuracy of the test results, and the reference point was chosen to be consistent with that used during the 1997 flight testing, allowing direct comparison of the data from the two tests.

Prior to collecting data, the equipment and test configurations including couplers, cables, and any part in the signal string(s) which could influence the outcome of the test needed to be carefully measured so that amplitude offsets in the data collected could be removed. There are two possible approaches to carrying out this type of calibration; In the first, each item to be used is measured at the frequencies of interest, and in the final test setup, these losses and gains are summed. The drawback is that the losses and gains are small, and that the measurement errors for each individual component add, thus the resulting information contains potentially large cumulative errors. The second, preferred approach, (which was utilized) is to assemble the entire signal string – end to end – and measure the combined gain/loss in one or two segments. One to two measurements is best, as it accumulates the measurement inaccuracy of the calibrating equipment only once or twice.

In this case, an HP 8656B signal generator was utilized as an amplitude reference, and gain/loss measurements were made by alternately applying the test signal to a spectrum analyzer directly, and then to the analyzer (without changing settings) through the path under test. The observed difference was the gain or loss through the path. In this way, the added test cables to facilitate the hookups, as well as the *absolute level* inaccuracy of the signal generator and spectrum analyzer canceled. The measurement inaccuracy became simply the amplitude linearity of the spectrum analyzer, which was an HP-8594E in current calibration. Referring to published specifications, the resulting measurement inaccuracy was ±0.3 dB ±0.01 dB per dB below the reference line. In this case the total inaccuracy was always less than ±0.8 dB with the strictest reading, but in a comparative reading as was used, one might expect ±0.5 dB provided all measurements are conducted in the 20dB range below the reference. To assure accuracy throughout extended testing, equipment was left on, large ambient temperature excursions were avoided, and a postcalibration was performed prior to equipment teardown to check for gain/loss drift. Observed drifts were about ½ dB, within expected measurement repeatability.

Six paths, shown in Figure 3.1 were calibrated, including couplers and cables;

1) From the HP8656B to the BTS multicoupler input A (-24.1 dB)
2) From the PNG7112 to the BTS multicoupler input A (-23.0 dB)
3) From the Duplex OUT port of the HP8921 to the BTS multicoupler input A (-2.5 dB)
4) From the BTS multicoupler input A to the HP8591E (35.3 dB)
5) From the BTS multicoupler input A to the BTS transceiver (TRU) under test (4.4 dB)
6) From BTS Transmit output to the RF IN/OUT port of the HP8921 (-0.8 dB)

Note: that these measurements were taken at AMPS channel 300 (reverse or forward frequency, as appropriate), utilized by the HP8921 for all BER testing. "+" denotes path gain, "-" denotes a path loss.

3.3 Receiver Bit Error Rate Test – Data Collection

To perform data collection, the operator first set the desired reverse channel broadband noise and AMPS interference levels, *referenced to the input of the Base Station multicoupler.*
(The initial path calibration discussed above provided an offset value which was applied to the signal generator levels, compensating for the RF path losses between the test set and Base Station multicoupler input.)

The sample size (the number of frames) to be used for the BER calculation is a configurable value in the HP test software. Small sample sizes allow faster measurements, at the cost of measurement accuracy and precision. Larger sample sizes improve accuracy and precision, but increase test time. It was important to achieve measurement accuracy and precision. Sample size was set at 250 frames of 260 bits each, for a total of 65,000 bits per BER measurement. At this sample size, each data point (BER value) took 2-3 minutes to measure. This was chosen as the best balance between ultimate accuracy and test time, as hundreds of data points were to be taken. This choice translated into a test duration of approximately a week to characterize one receiver.

To provide a confidence check that the site transceiver (TRU) under test was not unusual in some way, two more radios were obtained, and a subset of the data rerun, changing only the radio in the test setup. Full characterization of these radios wasn't necessary, as their performance proved similar to that of the TRU that had been fully tested.

3.3.1 Background Noise Simulation

The effects of noise, diffuse man-made background interference and distributed traffic in the terrestrial network was simulated by a precision noise generator, which was used to inject additive white gaussian noise into the reverse channel path. Variation of the noise level produced measurements representative of various conditions that occur in the real world. Rural, Suburban, Urban, and Dense Urban environments were simulated in this way.

Five broadband interference levels were injected:

- None – Thermal noise only (-174 dBm/Hz.)
- -118 dBm in 30kHz. – typical of Rural environments
- -115 dBm in 30 kHz. – typical of Suburban environments
- -107 dBm in 30 kHz. – typical of Urban environments
- -100 dBm in 30 kHz. – typical of Dense Urban Environments.

3.3.2 AMPS Interference Simulation

The simulated AMPS interferer was an FM modulated radio frequency carrier. Both AMPS and TDMA utilize the same 30kHz channelization, so only one AMPS channel is cochannel to a given TDMA channel. AirCell must plan its own frequency reuses in a way that prevents self-interference, and this planning prevents more than one airborne interferer from being co-channel with a given ground TDMA channel at a given site. If two or more aircraft utilized the same frequency in proximity to an observer site, the AirCell calls would act as interference sources to each other – clearly not a practical scenario. In the test setup, the AMPS interferer was linearly combined with the additive white gaussian noise to create the composite noise level and narrowband interference to be added to the reverse channel path.

The modulation choice for the interferer required some consideration. AMPS signals may carry Supervisory Audio Tone (SAT), Signaling Tone (ST), digital FM data, and/or voice. The most disruptive modulation to a QPSK signal was chosen. To make this choice, one must consider the IS-136 modulation scheme. Quoting the specification, (TIA/EIA 136-131):

"The modulation method used is known as $\pi/4$ shifted, differentially encoded quadrature phase shift keying. The modulation scheme uses the phase constellation shown in Figure 3.2. Note that Gray code is used in the mapping; two di-bit symbols corresponding to adjacent signal phases differ only in a single bit. Since most probable errors due to noise result in the erroneous selection of an adjacent phase, most di-bit symbol errors contain only a single bit error. Note also, the rotation by $\pi/4$ of the basic QPSK constellation for odd (denoted ⊕) and even (denoted ⊗) symbols.

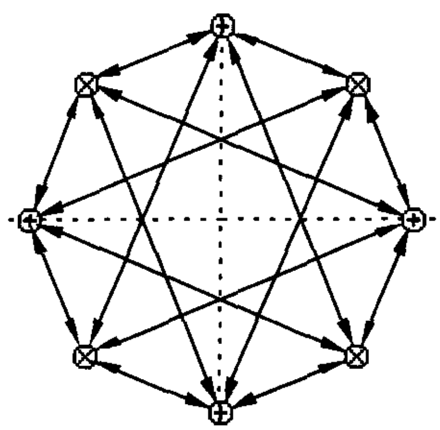


Figure 3.2 IS-136 S-plane Signal Constellation

The information is differentially encoded; symbols are transmitted as changes in phase rather than absolute phases. A block diagram of the differential encoder is shown in Figure 3.3. The binary data stream entering the modulator, b_m, is converted by a serial-to-parallel converter into two separate binary streams (X_k) and (Y_k). Starting from bit 1 in time of stream b_m, all odd numbered bits form stream X_k and all even numbered bits form stream Y_k."

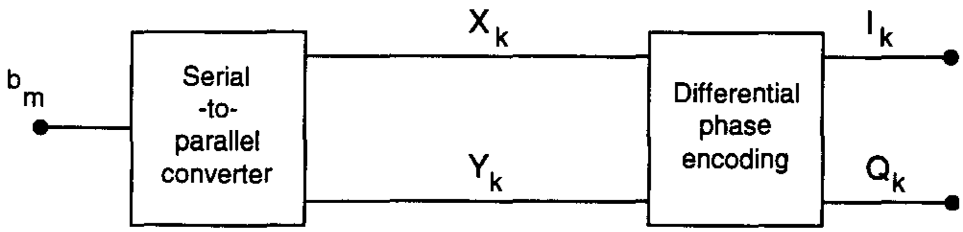


Figure 3.3 Differential Encoder

The digital data sequences (X_k) and (Y_k) are encoded onto (I_k) and Q_k) according to:

$$I_k = I_{k-1} \cos[\Delta\Phi(X_k, Y_k)] - Q_{k-1} \sin[\Delta\Phi X_k, Y_k)]$$
$$Q_k = I_{k-1} \sin[\Delta\Phi(X_k, Y_k)] - Q_{k-1} \cos[\Delta\Phi X_k, Y_k)]$$

where I_{k-1}, Q_{k-1} are the amplitudes at the previous pulse time. The phase change $\Delta\Phi$ is determined according to the following table:

Table 3.1 Phase changes

X_k	Y_k	$\Delta\Phi$
1	1	$-3\pi/4$
0	1	$3\pi/4$
0	0	$\pi/4$
1	0	$-\pi/4$

The signals I_k, Q_k at the output of the differential phase encoding block can take one of five values, 0, ±1, ±1/√2 resulting in the constellation shown in Figure 3.2."

In effect, this remains a coherent QPSK signal, but the phase reference is the last detected symbol, not a recovered carrier tone. The decision region boundaries for a ⊗ symbol period are the dotted lines shown along the real and imaginary axes. The theory behind this choice is presented in a number of texts, but what is important here is that these decision regions are optimal for a gaussian noise case... and may not be optimal choices in the presence of interference. The most disruptive interferer is a coherent sinusoid which *offsets* the constellation relative to the decision regions. AMPS never produces such a signal. The closest it can come to CW is SAT-only during quiet moments on a voice channel, making SAT-only the logical choice for the worst-case AMPS interference.

This hypothesis was tested by measuring the BER vs. interference performance for:

- A coherent CW tone (with the HP8921 and HP8656 sharing a single timebase)
- A CW tone (with the HP8921 and HP8656 timebases disconnected from each other)
- SAT only
- ST modulation.

The results, using a constant -110 dBm interferer level, are shown below:

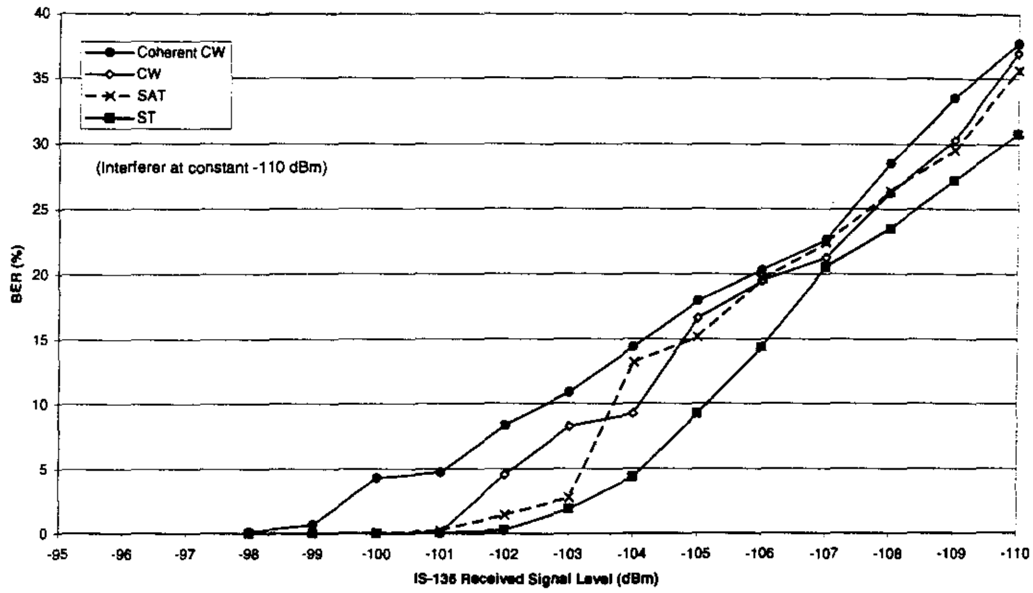


Figure 3.4 Relative impact of various modulations on IS-136 Bit Error Rate

SAT *plus* voice modulation was not tested because one can reasonably expect that it will appear 'less coherent' and more 'noiselike' to an IS-136 demodulator than SAT alone. One would expect it to fall between the SAT and ST cases in terms of disruptive potential. It was also ruled out from a test logistics point of view, as it would have been very difficult to use the *same moment* of a speech clip in synchronism with each BER measurement taken. This would have been necessary so its influence would have been consistent (repeatable) across all measurements.

Based on this reasoning and the data in Figure 3.4, SAT-only modulation was chosen as the most disruptive interferer AMPS could offer, and all later BER measurements utilized this as the 'AMPS interferer'.

It's useful to note that this choice is a somewhat unfavorable test condition to AirCell, as one can reasonably expect that intervals of FM modulated speech on the reverse link will create an influence somewhere between that of the SAT alone and ST cases, which lie up to about 2 dB apart (on the RSSI axis, for a constant BER). Thus, speech on the AirCell reverse channel may 'appear' to be at a 0-2 dB lower received power than a signal modulated by SAT alone, resulting in an overestimate of interference herein.

3.3.3 Bit Error Rate in the presence of interference

To characterize the cell site receiver over varying signal and interference inputs, the HP8921A Cell Site Test Set was programmed with an IBASIC routine (HP11807B, with slight modifications). The software was modified so that iterative testing with varying TDMA signal level could be automatically accomplished. The operator selected the start, stop and step size for the TDMA signal level. Each of the other operating parameters, broadband noise and AMPS interference, were set manually and the measurement sequence was initiated. The values of each system variable and the BER results were recorded, both to collection logfiles, and manually entered into Excel spreadsheets. The detailed procedure was as follows:

- The equipment at the Lena Cell site was set up as shown in Figure 3.1.
- The transceiver under test was isolated from carrying customer call traffic by appropriate manipulation of the hardware and switch software, including:
  - The BTS 'marked off' the transceiver to be tested, allowing the local control the HP Base Station Test Set requires to test the transceiver.
  - The transceiver to be tested used one isolated diversity RX path, disconnected from active site antennas. (This allowed the test to be run in daylight hours, without interrupting other site traffic, which continued to operate using the other diversity path.)
- Calibration of RF paths at Forward or Reverse Band frequencies, as appropriate, was accomplished and path losses/gains recorded. <u>Offsets were then applied to power settings detailed below to correct for these path losses/gains</u>, presenting the multicoupler input with the levels specified. <u>All testing referenced reverse path levels at the input of the antenna multicoupler.</u>

After setup, data collection steps were (indentation corresponds to nesting of iterations):

- Set the noise generator to a specified value. ('Off' for the first - thermal noise floor, run)
  - Set AMPS interferer at a specified starting point (–124 dBm for the first run), referenced to the input to the receive multicoupler.
    - Set the HP8921 to transmit at a starting value (–120 dBm for the first run), referenced to the same point, and begin programmed iteration, stepping the TDMA power level. The HP 8921 will:
      - Obtain a reverse channel BER reading.
      - Output the reverse channel BER reading to a logging computer via a serial port for later verification, if desired.
      - Display the reading and beep, allowing the human operator to manually record the BER value into an Excel spreadsheet. (Each measurement takes 2-3 minutes, so this encourages the operator to watch the data collection for anomalies)
      - Increment the HP8921 transmit power 1dB
      - Repeat until reaching a preset endpoint transmit level. (–100 dBm for the first run)
  - Repeat, setting AMPS interferers 2 dB higher each iteration, until reaching the specified endpoint (-90dBm for the first run).
- Repeat above runs with the Noise generator turned on, set at a noise power spectral density corresponding to:

-118 dBm total power in 30kHz,	(simulating Rural noise levels)
-115 dBm in 30kHz,	(simulating Suburban noise levels)
-107 dBm in 30 kHz,	(simulating Urban noise levels)
-100 dBm in 30 kHz	(simulating Dense Urban noise levels)

HP 8921 iterative test limits were set to obtain a large BER (over 25%) on the first step, and TDMA (desired signal) power was increased in 1 dB steps until the BER converged on zero. The power limits were set as required to provide these results with the background noise and interferer level chosen for the run. The completed matrix for each noise level was filled into a template:

(The X's shown represent BER data points to be taken.)

Table 3.2 Example Excel spreadsheet template for receiver characterization

%BER at -174 dBm Noise Floor – KTB
188 data points

TDMA Carrier (dBm)

[illegible]																
[illegible]																
[illegible]											X					X
[illegible]										X	X		X		X	X
[illegible]									X	X	X	X	X	X	X	X
[illegible]								X	X	X	X	X	X	X	X	X
[illegible]							X	X	X	X	X	X	X	X	X	X
[illegible]						X	X	X	X	X	X	X	X	X	X	X
[illegible]					X	X	X	X	X	X	X	X	X	X	X	X
[illegible]				X	X	X	X	X	X	X	X	X	X	X	X	X
[illegible]			X	X	X	X	X	X	X	X	X	X	X	X	X	X
[illegible]		X	X	X	X	X	X	X	X	X	X	X	X	X	X	
[illegible]	X	X	X	X	X	X	X	X	X	X	X	X	X	X		
[illegible]	X	X	X	X	X	X	X	X	X	X		X	X			
[illegible]	X	X	X	X	X	X	X	X	X			X				
[illegible]	X	X	X	X	X	X	X	X								
[illegible]	X	X	X	X	X	X	X									
[illegible]	X	X	X	X	X	X										
[illegible]	X	X	X	X	X											
[illegible]	X	X	X	X												
[illegible]	X	X	X													
[illegible]	X	X														
[illegible]	X															
	-124	-122	-120	-118	-116	-114	-112	-110	-108	-106	-104	-102	-100	[illegible]	[illegible]	[illegible]

AMPS Interferer (dBm)

Notes:

1- The outer iterative loop shown has 5 steps total, each of which yielded a spreadsheet page as shown in Table 3.2 above. The intermediate (AMPS interferer power step loop) has 16 steps, and the automated inner loop (HP8921 transmit power) has about a dozen steps (which may vary as the desired BER limits are found). Thus the data collection required 80 manual setup/collection iterations, each producing about a dozen data points, for a total of 960 data points in the 5 Excel result spreadsheet pages. At about 3 minutes per data point, collecting these 5 spreadsheet pages required 48 hours of data collection. Collection time is only significant in that it is driven by the length of the sample used to calculate BER. The choice made represented an upper limit to practical collection, and yielded acceptable accuracy.

2- Data was taken manually (directly into an Excel spreadsheet) in addition to logging via computer because: The 8921 did not control the interference and noise signal generators, so it could not log their settings directly (a human operator had to be present to log/change them). Second, the modified HP software (with changes verified by SAFCO and WSE) produced a large amount of hard-to-parse ASCII output to the logfile, and it occasionally failed to produce a valid data point. The usual problem was a failure to synchronize BER test patterns within the HP 8921. Such missing points had to be retaken, which meant human intervention. Prompt retakes of data points were best ensured if a human was present, noting the data as it came in.

3.4 Results – BER vs. signal level in the presence of AMPS interference

The first table taken was one for receiver performance with only an AMPS interferer added. That is, no deliberate wideband noise was injected - the precision noise source was disabled.

Table 3.3 Cell site performance in thermal noise with AMPS interference.

[illegible]																			0.00
[illegible]			%BER at -174 dBm Noise Floor – KTB															0.00	0.00
[illegible]												0.00					0.00	0.00	0.00
[illegible]											0.00	0.00		0.00		0.00	0.00	0.01	0.62
[illegible]										0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.74	9.52
[illegible]									0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.82	8.26	19.90
[illegible]								0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.75	8.40	19.18	24.34
[illegible]							0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.63	7.75	19.29	24.89	35.64
[illegible]						0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.35	7.14	18.20	25.18	35.57	
[illegible]					0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.94	8.42	19.14	25.28	35.88		
[illegible]				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.77	12.35	19.86	23.39	37.38			
[illegible]			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	4.75	10.61	18.92	23.08	35.02				
[illegible]		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.55	8.33	19.28	24.57	35.05					
[illegible]		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.56	12.91	19.55		34.33						
[illegible]		0.00	0.00	0.00	0.00	0.01	0.04	1.31	8.25	20.09									
[illegible]		0.00	0.00	0.00	0.00	0.14	1.32	9.37	20.23										
[illegible]	0.00	0.01	0.00	0.03	0.56	1.79	8.54	19.19											
[illegible]	0.00	0.06	0.42	1.32	3.62	13.81	19.62												
[illegible]	0.03	0.79	4.96	4.74	11.31	21.24													
[illegible]	0.54	6.23	7.74	16.02	22.42														
[illegible]	2.90	15.01	16.66	23.42															
[illegible]	10.13	19.05	25.19														Retested This Point		
[illegible]	16.05	27.86																	
	OFF	-124	-122	-120	-118	-116	-114	-112	-110	-108	-106	-104	-102	-100	-98	-96	-94	-92	-90

AMPS Interferer (dBm)

Looking at this table, each column represents an automated, iterative run made by the HP8921. Moving from one column to the next involved manual changes to the AMPS interferer level.

The column labeled 'OFF' in Table 3.3 is the receiver's performance in thermal noise only… (In Table 3.4 through Table 3.7, the 'OFF' column is performance with broadband noise only, and no narrowband interference.)

Published specifications (TIA/EIA-136-280, paragraph 2.3.2.1.1.3, Table 4) call for 3% BER at –110 dBm. This site achieves 3% BER at a –116 dBm input level. This receiver appears to be performing substantially better (6 dB) than the standard requires. As a result, it should 'see' interference – a degradation to its received BER – at levels below those imposed by industry standard. *This is a worse than necessary case from the AirCell point of view...*

(Note that these results were obtained under static -non fading- laboratory conditions, with no man-made noise background… The receiver *would not* perform well at -116 dBm under 'real world' conditions.)

Noting that this table contained an excessive number of zero values, it was determined that substantial data collection time could be saved -without losing useful data- by terminating runs as soon as it had converged on zero BER for 2-3 readings.

Note: In some cases, the HP 8921 test set would not synchronize the received data stream with that transmitted. This happened intermittently, at various BER values. When this occurred, the test set would not report a BER value. To prevent an incomplete table, the operator would manually rerun 3-5 data points around the missing value(s). They would be checked for consistency with the points surrounding the missing value, and if agreement was good, the missing value would be entered. Points retested in this way are highlighted in yellow in this table and those that follow.

If points were tested at the high end of the BER range, and error rates were high enough (over about 35%) to prevent 'lock' and measurement of a value, 50% BER...the worst case, was inserted.

Originally, it was believed that incrementing the TDMA carrier level in 2 dB steps would provide good resolution. Table 3.3 shows this did not prove to be the case. The typical design point for TDMA systems is 1-2% BER, and the curve is extremely steep in this region. Clearly, additional resolution is useful, and later collection runs were changed to 1 dB TDMA signal amplitude steps.

While the thermal noise limited case is interesting, it is not truly representative of real-world operation at a cell site. Man made noise from various sources is generally recognized to exist; and its' amplitude is related to population density. Activating the precision noise generator allowed simulation of various land use conditions. Table 3.4 shows the rural condition:

Table 3.4 Cell site performance with 'Rural' background noise level and AMPS interference.

TDMA Carrier (dBm)

[illegible]																			
[illegible]		%BER at -118dBm Noise Floor - Rural																	
[illegible]																			
[illegible]																			0.00
[illegible]																			0.00
[illegible]																		0.00	0.00
[illegible]																		0.00	0.70
[illegible]																	0.00	0.03	2.05
[illegible]																	0.00	0.30	7.24
[illegible]																0.00	0.07	3.13	12.30
[illegible]																0.00	0.70	8.28	18.34
[illegible]															0.00	0.06	2.42	15.28	21.92
[illegible]															0.10	0.80	6.83	19.04	25.08
[illegible]														0.00	0.03	6.35	15.58	21.29	
[illegible]														0.02	0.41	8.45	20.20	25.06	
[illegible]													0.00	0.16	3.57	13.16	22.94		
[illegible]													0.01	1.02	9.47	19.22	24.87		
[illegible]												0.00		8.17	14.60	22.03			
[illegible]											0.00	0.07	0.56	8.09	20.05	25.36			
[illegible]										0.00	0.00	0.28	4.19	14.40	21.70				
[illegible]									0.00	0.00	0.06	1.54	13.01	19.36	25.65				
[illegible]								0.00	0.00	0.02	0.16	3.82	15.70	21.82					
[illegible]							0.00	0.00	0.00	0.12	0.85	7.36	20.41	24.50					
[illegible]						0.00	0.00	0.00	0.07	0.32	4.53	17.16	20.96						
[illegible]		0.00	0.00	0.00	0.00	0.00	0.00	0.03	0.32	2.24	9.30	20.41	25.14						
[illegible]		0.00	0.00	0.00	0.00	0.01	0.03	0.15	1.06	5.59	17.22	22.46							
[illegible]		0.00	0.00	0.00	0.00	0.02	0.12	0.57	2.07	9.65	20.43	26.83							
[illegible]	0	0.00	0.00	0.01	0.02	0.13	0.27	4.50	6.53	16.82	23.08								
[illegible]	0	0.01	0.00	0.03	0.11	0.44	0.88	4.31	10.21	20.42	26.63								
[illegible]	0.02	0.04	0.06	0.12	0.47	1.34	3.69	12.88	18.42	23.65									
[illegible]	0.09	0.20	0.23	0.75	1.08	2.48	11.64	15.52	21.40	27.09									
[illegible]	0.23	0.62	0.64	1.42	2.25	5.99	13.66	19.41	24.05										
[illegible]	0.71	1.11	1.80	2.90	4.86	13.00	12.96	22.08	27.16										
[illegible]	1.65	2.71	3.03	5.05	8.34	12.86	19.86	24.78											
[illegible]	3.21	5.31	6.15	9.60	13.43	17.06	22.91												
[illegible]	5.40	10.26	10.07	13.89	15.89	21.36													
[illegible]	8.16	12.14	17.16	18.57	21.84														
[illegible]	11.62		19.08																
[illegible]	19.70	18.70	23.03																
[illegible]	20.83	23.70																	
[illegible]	23.56	25.27																	
[illegible]	26.65	29.53																	
[illegible]	31.88	32.23																	
[illegible]	32.44	34.91																	
[illegible]	35.93	37.98																	
	OFF	-124	-122	-120	-118	-116	-114	-112	-110	-108	-106	-104	-102	-100	-98	-96	-94	-92	-90

AMPS Interferer (dBm)

This table contains two omissions – a data point was not obtained in the -124 dBm interferer column, and one was not obtained in the -102 dBm interferer column. The H-P test set failed to obtain 'DSP Sync' on the received data pattern when testing these points, and due to human error the points were not retaken. Interpolation may be used to bridge such missing points.

It is clear that the introduction of background noise raised the TDMA signal level required to obtain a given BER. The 2% BER point generally falls 8 dB above the larger of the noise or AMPS interference, and in this case, 11 dB higher when the two forms of interference were equal at –118 dBm. This is logical, as the two powers add and raise the 'apparent' (combined) interference level by 3dB. (When they are significantly unequal, one or the other predominates.) This produces a 3 dB shift from 8 to 11 dB S/I (relative to either interferer alone) required to attain 2% BER. This expected behavior helps to confirm the data collection approach was operating properly.

Next, wideband noise simulating Suburban conditions was selected, and Table 3.5 resulted. Again, 7-8 dB of S/I was required to reach 2% BER, and a roughly 3dB jump manifested where both interference levels were the same.

Table 3.5 Cell site performance with 'Suburban' background noise level and AMPS interference.

TDMA Carrier (dBm)

OFF	-124	-122	-120	-118	-116	-114	-112	-110	-108	-106	-104	-102	-100	-98	-96	-94	-92	-90
	%BER at -115dBm Noise Floor - Suburban																	
																		0.00
																		0.00
																	0.00	0.01
																	0.00	0.04
																0.00	0.00	0.25
																0.01	0.00	2.21
																0.00	1.48	7.79
															0.00	0.01	1.97	12.89
															0.01	1.05	8.34	17.81
														0.00	0.05	2.32	13.67	20.76
													0.00	0.01	0.88	8.90	19.01	25.19
													0.00	0.07	3.11	12.76	21.14	28.04
												0.00	0.02	0.41	8.34	17.95	24.25	35.94
												0.01	0.11	2.62	14.81	21.62	30.81	40.20
												0.03	0.54	6.49	18.58	24.78	36.26	50.00
										0.00	0.00	0.35	3.23	14.36	21.78	30.08	39.75	50.00
									0.00	0.00	0.08	1.50	7.95	18.48	24.82	36.72	50.00	
								0.00	0.00	0.00	0.43	3.88	15.54	23.61	30.69	39.75	50.00	
								0.00	0.02	0.10	1.45	10.72	19.07	24.62	36.74	50.00		
					0.00		0.00	0.00	0.07	0.75	4.86	12.95	22.50	29.27	38.52	50.00		
					0.00	0.00	0.01	0.05	0.32	1.47	9.54	20.28	25.92	35.40	50.00	50.00		
		0.00	0.00	0.00	0.00	0.00	0.04	0.10	1.31	5.35	16.91	22.19	30.72	39.41	50.00			
0.00	0.00	0.00	0.00	0.00	0.02	0.06	0.24	0.90	2.65	9.36	18.86	25.89	35.46	50.00	50.00			
0.00	0.00	0.01	0.03	0.01	0.09	0.12	0.74	2.33	6.62	18.16	21.71	30.51	39.38	50.00				
0.01	0.02	0.03	0.04	0.06	0.16	0.54	1.32	4.60	10.27	17.50	25.91	35.44	50.00	50.00				
0.08	0.06	0.13	0.29	0.27	0.62	1.75	2.98	13.13	14.63	24.02	30.97	38.50	50.00					
0.25	0.26	0.40	0.38	0.73	1.65	3.11	11.78	13.19	19.02	27.81	35.39	50.00	50.00					
0.69	0.70	0.95	1.45	1.91	3.85	5.30	12.69	19.84	24.40	31.09	39.93	50.00	50.00					
1.56	1.96	2.09	3.05	3.52	6.20	9.08	17.24	23.31	27.86	36.47	41.92							
2.80	3.10	4.41	4.61	6.51	9.41	13.06	17.64	24.80	31.09	38.99	50.00							
4.85	5.35	8.05	8.43	11.46	12.52	20.24	22.93	28.92	35.04	50.00	50.00							
8.38	7.72	11.03	11.06	18.86	18.86	23.51	28.51	32.84	39.05	50.00	50.00							
12.20	16.45	17.74	17.60	17.34	22.00	25.85	30.83	35.80	41.79	50.00	50.00							
17.16	18.89	18.72	19.64	21.88	25.45	29.42	33.62	39.90	50.00	50.00								
20.19	21.24	22.31	23.02	25.86	29.50	32.43	37.41	50.00	50.00									
23.39	22.38	24.15	25.97	28.54	31.78	35.48												
26.29	27.86		29.18	31.64	34.69													
29.38															Repeated this point			
32.60																		

AMPS Interferer (dBm)

Table 3.6 Cell site performance with 'Urban' background noise level and AMPS interference.

TDMA Carrier (dBm)

OFF	-124	-122	-120	-118	-116	-114	-112	-110	-108	-106	-104	-102	-100	-98	-96	-94	-92	-90
																		0.00
	%BER at -107 dBm Noise Floor – Urban																0.00	0.01
																	0.00	0.03
																0.00	0.00	0.00
																0.00	0.02	2.62
															0.00	0.19	0.57	1.86
															0.00	0.07	2.00	9.00
														0.00	0.02	0.39	4.05	6.28
														0.00	1.76	0.52	6.06	12.96
													0.00	0.12	0.76	4.11	9.67	15.99
												0.00	0.13	0.00	1.03	6.50	13.24	18.19
											0.00	0.00	0.00	0.85	0.28	9.71	17.28	23.36
									0.00	0.00	0.00	0.03	0.31	1.33	7.69	13.34	20.56	26.09
									0.00	0.00	0.00	0.28	0.82	3.36	10.88	16.87	22.51	32.86
	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.04	0.34	2.01	7.97	14.77	20.27	26.01	
	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	1.00	5.11	12.20	18.04	23.83	32.60	
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.06	0.70	2.80	8.92	14.02	19.79	27.53		
0	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.02	0.06	0.17	4.97	7.13	11.98	18.12	23.50	32.34		
0.02	0.03	0.02	0.02	0.01	0.02	0.03	0.08	0.08	0.45	1.76	6.43	11.32	16.30	19.82	28.71			
0.03	0.06	0.04	0.06	0.11	0.10	0.13	0.33	0.37	2.90	2.99	9.84	13.22	17.24	24.44	32.62			
0.11	0.14	0.13	0.16	0.21	0.20	0.46	0.42	1.20	2.32	6.81	10.93	13.12	21.51	27.91				
0.38	0.54	0.67	0.42	0.70	0.73	1.12	1.94	3.67	8.72	10.52	14.14	17.32	24.93	32.06				
1.05	1.26	1.31	1.34	1.45	1.60	3.89	4.99	8.39	11.08	12.19	16.60	22.83	29.00					
2.08	2.48	2.50	2.56	2.88	3.02	3.67	6.09	11.88	13.50	14.69	20.52	26.27	32.73					
4.27	4.70	4.42	8.58	5.99	9.84	12.63	7.98	9.74	15.14	18.96	24.22	30.87						
6.28	6.80	8.54	8.40	12.45	8.06	13.14	14.09	14.57	18.74	22.46	27.31							
9.25	10.17	sync	14.68	15.06	15.09	15.98	17.25	19.46	22.03	26.68								
13.78	16.74	17.34	16.78	14.56	17.27	17.89	19.92	22.40	26.33									
19.54	20.32	19.17	18.78	20.88	19.82	21.75	22.20	25.26	28.89									
21.63	21.35	22.96	22.10	23.96	sync	25.05	27.11	29.39	32.27									
24.87	25.40	24.19	25.44	25.64	26.70	27.43	29.79	31.15	34.46									
27.56	28.36	27.73	27.45	28.65	30.89	30.00	32.18	33.71	37.17						Repeated this point			
30.15	31.43	30.94	31.30	32.09	32.74	33.38	35.08	36.84	39.95									

AMPS Interferer (dBm)

Table 3.7 Cell site performance with 'Dense Urban' background noise level and AMPS interference.

TDMA Carrier (dBm)

																		0.00
	%BER at -100 dBm Noise Floor – Urban Noisy																	0.00
																	0.00	0.00
																0.00	0.04	0.47
																0.00	0.00	0.09
														0.00	0.00	0.11	0.40	1.24
														0.00	0.00	0.73	2.52	6.65
				0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.29	5.76	1.01	9.07
			0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.01	0.24	5.10	9.66	12.75
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	1.10	0.18	7.84	11.23	16.99
0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.02	0.10	0.23	3.35	10.06	13.60	21.88
0.00	0.01	0.00	0.01	0.01	0.01	0.00	0.00	0.00	0.00	0.01	0.06	0.38	0.33	3.41	8.81	12.67	19.63	24.36
0.05	0.03	0.03	0.04	0.03	0.04	0.07	0.04	0.06	0.08	0.14	0.22	0.74	1.07	5.66	5.65	16.06	22.28	26.67
0.11	0.16	0.08	0.14	0.15	0.11	0.08	0.14	0.15	0.33	0.53	0.56	3.44	1.81	9.55	10.54	18.52	25.54	32.71
0.34	0.38	0.38	0.33	0.34	0.54	0.36	0.52	0.47	0.71	0.92	1.61	4.98	11.22	9.93	15.52	21.82	30.30	37.10
0.66	0.85	0.80	0.82	0.88	1.00	1.12	1.22	1.16	1.26	1.98	3.14	4.89	11.41	16.50	18.83	25.90	32.77	40.54
2.01	1.55	1.79	1.60	2.10	1.92	2.08	2.29	2.29	3.06	3.61	4.72	10.96	13.75	17.45	22.90	30.06	36.40	42.84
3.60	3.32	3.15	3.37	3.51	3.72	4.00	4.18	7.06	5.57	12.70	12.58	15.04	17.17	21.49	26.98	33.59	40.22	44.58
5.68	5.78	5.54	5.67	8.06	6.00	7.02	6.68	7.26	12.69	14.00	15.11	17.10	20.36	25.55	30.05	37.56	42.74	50.00
9.05	8.42	10.09	9.09	11.16	9.61	14.73	9.90	16.17	11.57	15.96	17.33	20.41	23.40	29.06	34.59	40.55	50.00	50.00
15.26	16.14	12.02	15.61	12.70	12.23	16.12	15.66	15.72	18.08	18.71	20.43	22.94	26.24	31.70	37.74	43.02	50.00	50.00
15.49	16.66	18.48	17.78	17.46	18.75	16.16	16.84	17.39	20.80	22.05	23.18	26.27	30.23	34.69	40.37	50.00	50.00	
21.01	20.66	21.99	20.84	20.98	21.46	21.98	21.61	21.79	23.93	25.04	26.74	30.76	33.93	37.65	42.76	50.00		
25.14	23.71	24.33	23.14	24.16	24.38	23.20	24.19	25.09	26.34	28.37								
27.50	27.26	27.50	26.44															
30.14	29.52	29.98														Repeated this point		
32.63	32.85																	
OFF	-124	-122	-120	-118	-116	-114	-112	-110	-108	-106	-104	-102	-100	-98	-96	-94	-92	-90

AMPS Interferer (dBm)

Table 3.6 and Table 3.7 follow in turn, and as the noise floor rose, the minimum useful TDMA signal level continued to rise in order to achieve acceptable operating bit error rates.

Table 3.4 through Table 3.7 form the basis for the cell site performance calculations which follow in later sections. Receiver data to this point was taken using a Nortel Dual Mode base station, through radio serial number 532LUJRV, which was chosen randomly.

Before using this data, the question arises: Is this radio representative of others of its type, or is its BER performance unusually good or bad? To answer this question, two more spare radios were used, again chosen randomly. They were plugged into the same cell site slot as the first radio, so path amplitude calibration data did not change.

The receive multicoupler path itself is essentially linear, and the gains fell within typical limits for Nortel equipment (per site documentation), so testing of multiple multicouplers was deemed unnecessary. The truly active device in the cell site signal string is the radio itself.

The data collection effort for Table 3.3 through Table 3.7 was on the order of a week. It was decided that characterization of the remaining two radios could be abbreviated without losing the desired performance confirmation. Four columns of data, evenly spaced, were taken per table rather than full characterization tables for each of the two additional radios, using the same test conditions applied in Table 3.3 through Table 3.7.

These abbreviated tables provide representative BER curves for varying interference levels. Using this data, all three radios' performance could be directly compared. Rather than reproducing the tabular data here, it's more illustrative to compare the receivers' BER performance vs. TDMA signal strength as a series of plots. In these plots, the first radio tested is designated "TRU 1" and the others "TRU 2" and "TRU 3"

First, consider the 'Rural Noise' case, in which the wideband noise generator was set to inject -118 dBm referenced to the site multicoupler input. Four columns of data were taken for each additional receiver, at -124 dBm, -114 dBm, -104 dBm, and -94 dBm AMPS interference level.

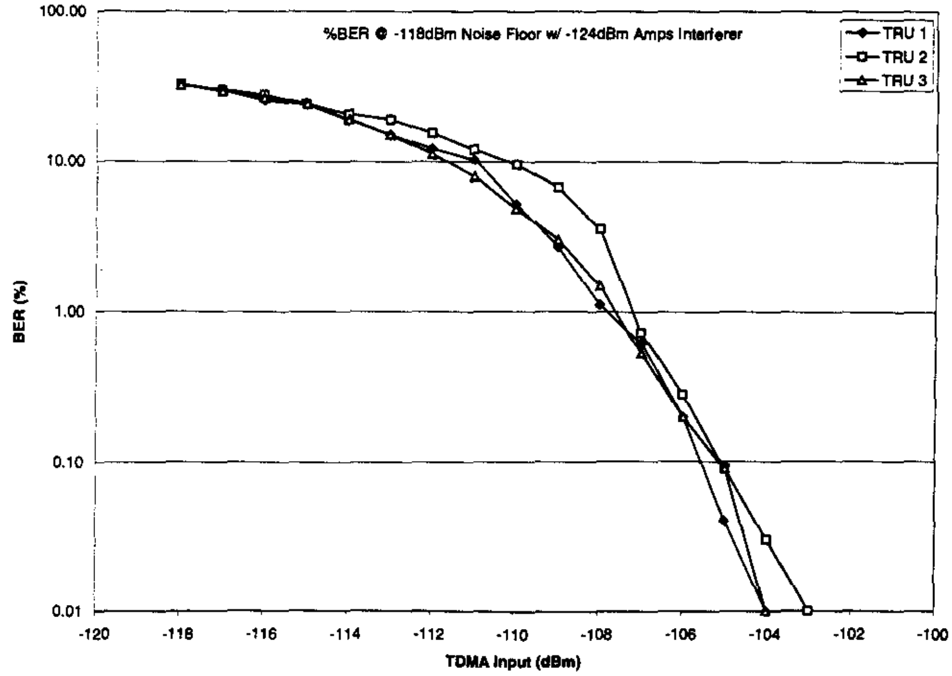


Figure 3.5 Receiver performance comparison, Rural Noise, -124 dBm AMPS interference

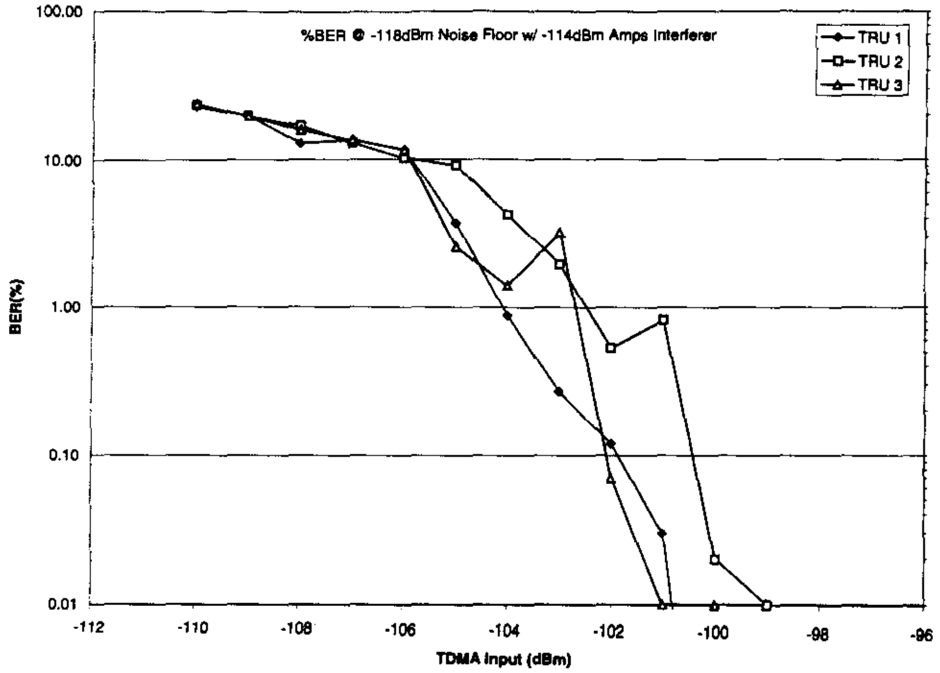


Figure 3.6 Receiver performance comparison, Rural Noise, -114 dBm AMPS interference

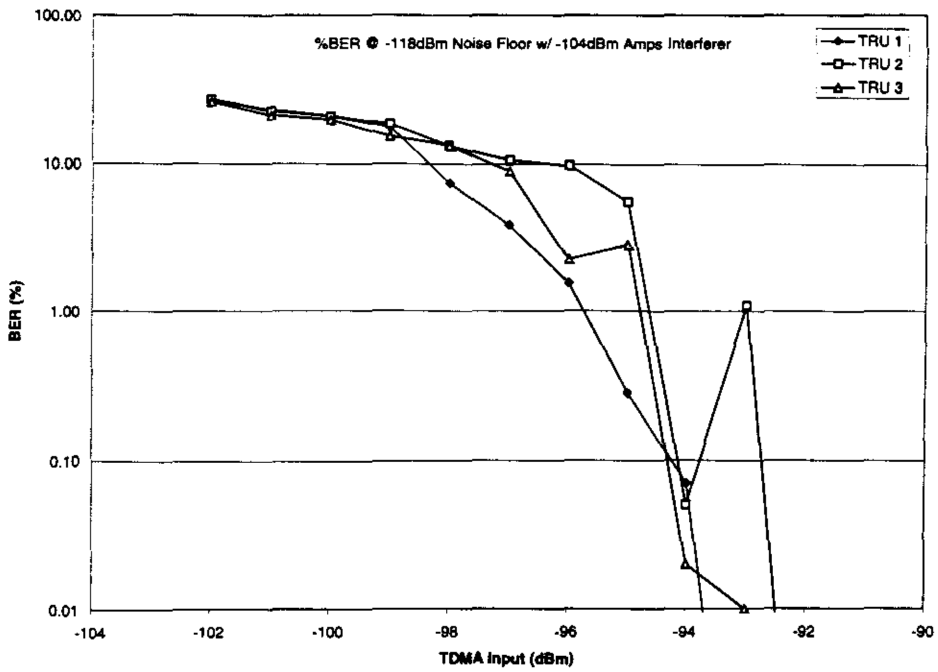


Figure 3.7 Receiver performance comparison, Rural Noise, -104 dBm AMPS interference

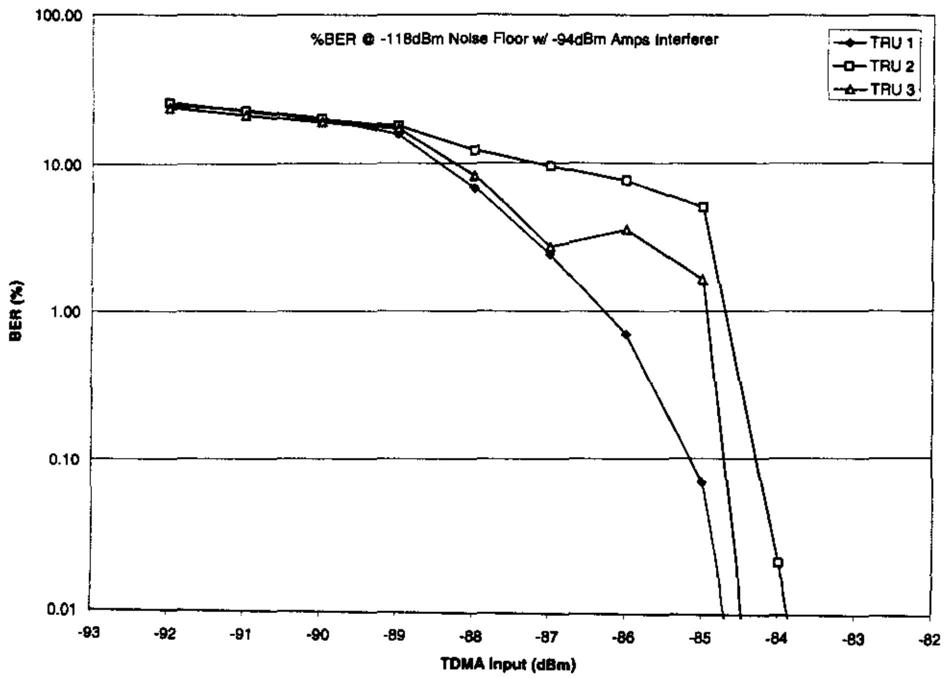


Figure 3.8 Receiver performance comparison, Rural Noise, -94 dBm AMPS interference

Examining Figure 3.5 through Figure 3.8, one sees that the first transceiver tested, (Nortel Serial #532LUJRV, designated "TRU 1", compares well with "TRU 2" (Serial #532LDC2H) and "TRU 3" (Serial #532LD95H).

The data is a bit noisy – in some places it's not perfectly monotonic as the TDMA signal increased, but that's to be expected, as the sample size is limited and in any phase-shift-keyed system, errors often come in bursts, due to demodulator reference phase slippages.

Overall, TRU 1 data seems to be *very slightly* 'better behaved' than the other two radios... having fewer 'flier points' in the data, and more of the classic 'waterfall' curve shape usually associated with BER characterizations. Later, when this data is interpolated and utilized in interference prediction, this should lead to better behaved calculations. (As noted earlier, the radios were randomly picked, and TRU 1 was tested first and most extensively. The other radios were tested to confirm that TRU 1 performance was typical. Radios weren't selected by performance.)

Note that one slight modification was made to the data prior to plotting the 'waterfall' curves. Logarithmic plotting can't handle a zero value. The HP test set resolves 0.01% as its' minimum BER, below which it reads 0.00%. For plotting purposes, 0.0001% was substituted for 0.00% readings from the test set. The only effect this will have on the plots is the apparent slope of the trace to the right of the last visible data point on each curve – This slope may vary a bit from 'true' performance, but it will not be as steep as would be plotted using raw HP test set data.

Raising the noise floor to 'Suburban' levels produces Figure 3.9 through Figure 3.12.

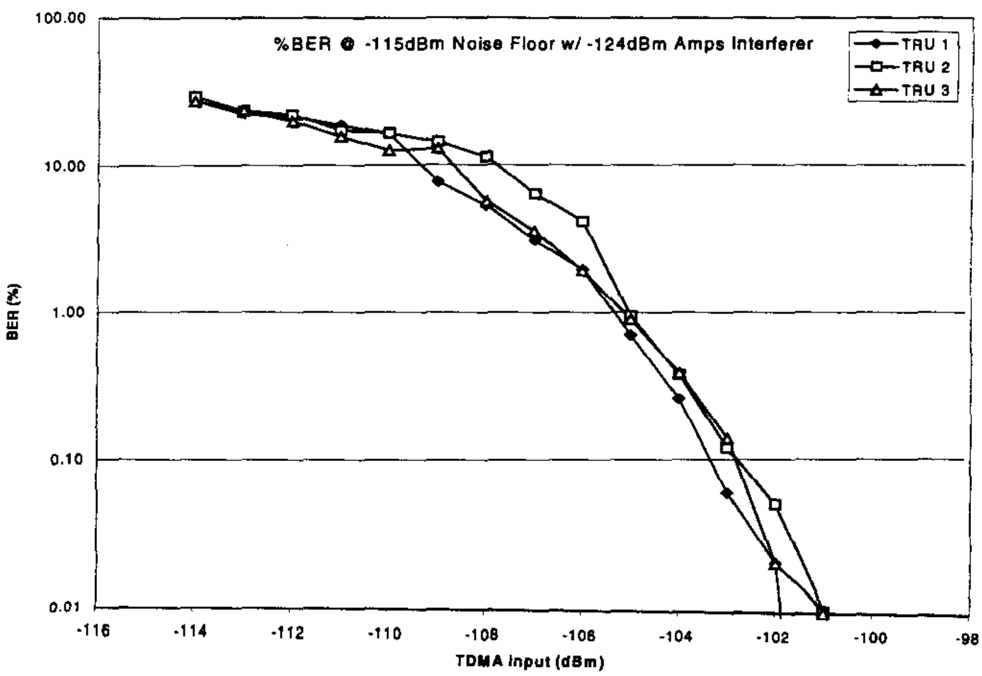


Figure 3.9 Receiver performance comparison, Suburban Noise, -124 dBm AMPS interference

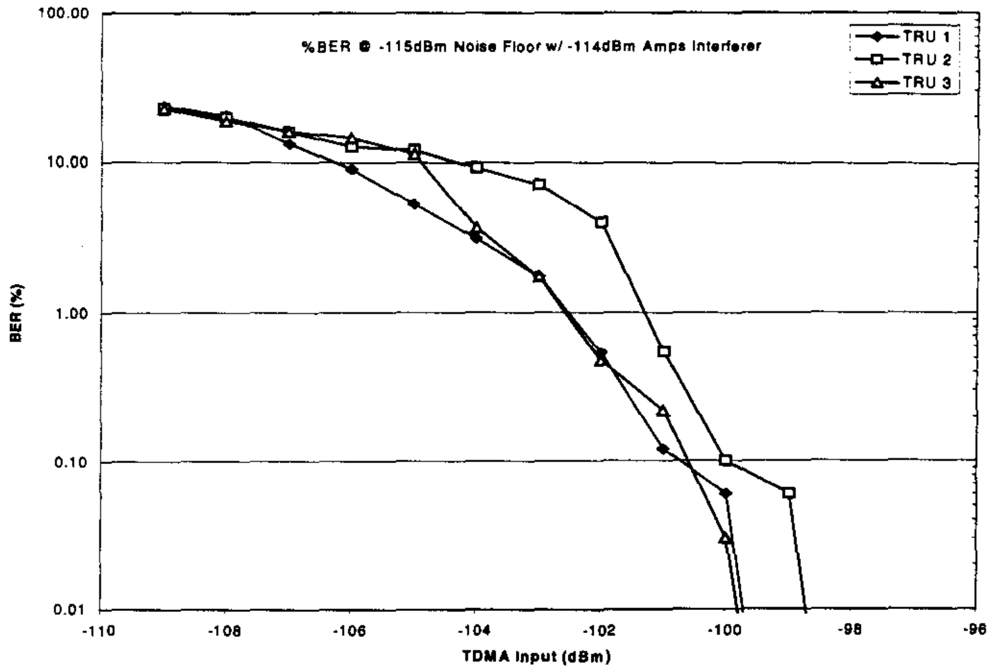


Figure 3.10 Receiver performance comparison, Suburban Noise, -114 dBm AMPS interference

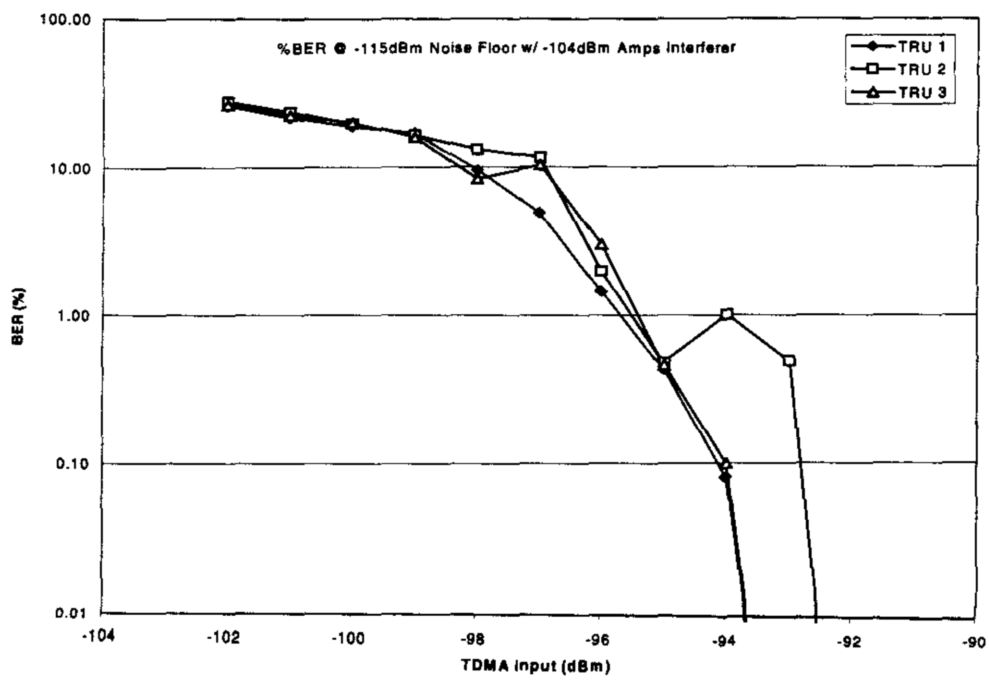


Figure 3.11 Receiver performance comparison, Suburban Noise, -104 dBm AMPS interference

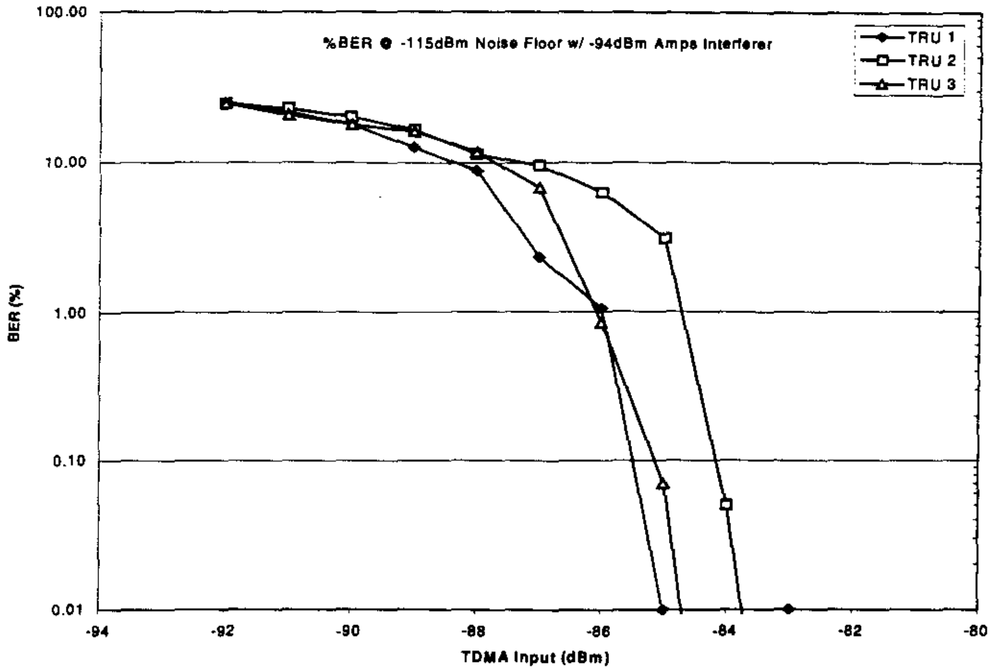


Figure 3.12 Receiver performance comparison, Suburban Noise, -94 dBm AMPS interference

Again, the receivers track similarly, within typical equipment production tolerances. TRU 2 is slightly worse (higher BER) than the other radios, and TRU 3 is sometimes better, sometimes worse, than TRU 1. The curves follow similar shapes, and if one looks at their separation horizontally on the plot, one finds that they're generally within 1-2 dB of each other at any given BER level, and often much closer.

Figure 3.13 through Figure 3.20 show comparative performance in Urban and Dense Urban noise conditions. In these conditions, TRU 1 is sometimes the poorer performer, having the highest BER over portions of the curve.

Overall, it was concluded that the performance for the three radios was comparable, and while one may perform marginally better than another over some signal ranges, given certain levels of interference, (during a single test run) there was no clear 'winner' whose performance was significantly better than another. The differences observed are believed to be a combination of normal production variations and the finite data sample length used to calculate BER data points. Therefore, the TRU 1 data was accepted as the performance baseline, and considered representative of other IS-136 base station radios.

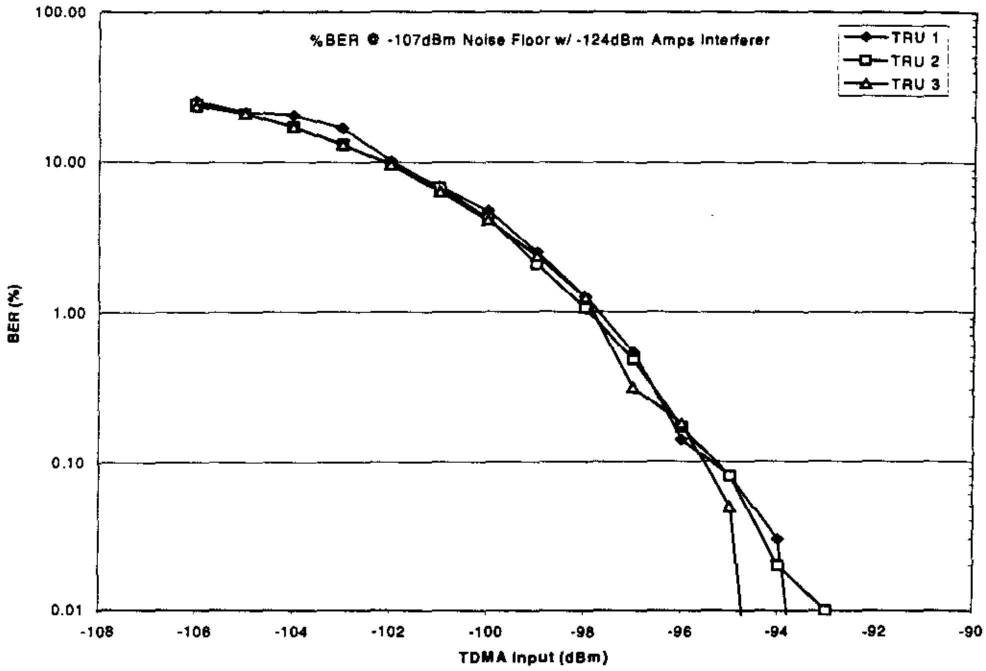


Figure 3.13 Receiver performance comparison, Urban Noise, -124 dBm AMPS interference

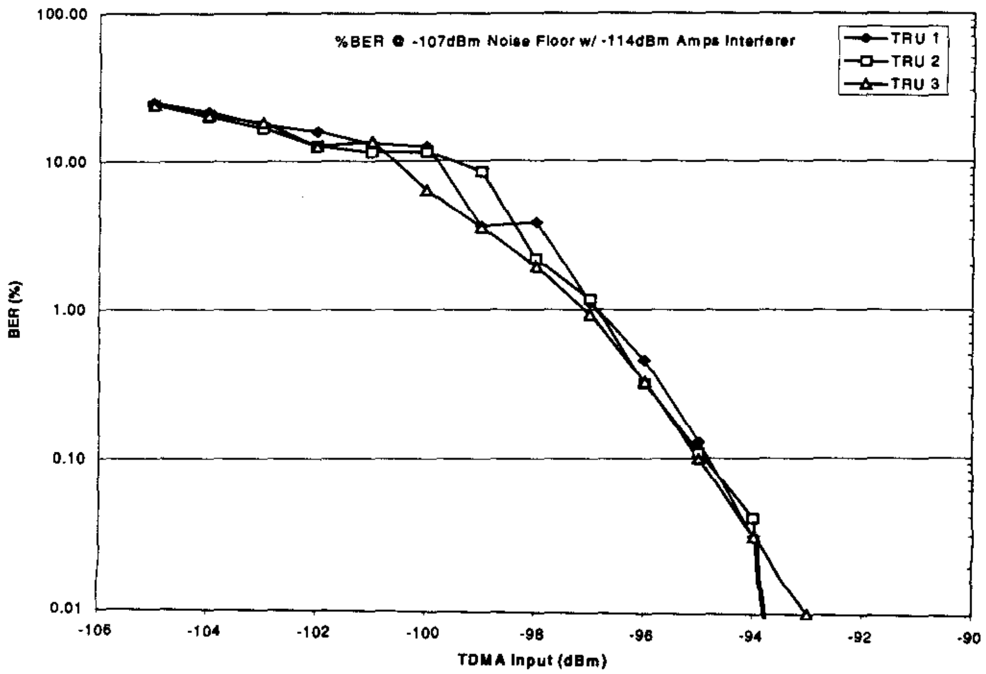


Figure 3.14 Receiver performance comparison, Urban Noise, -114 dBm AMPS interference

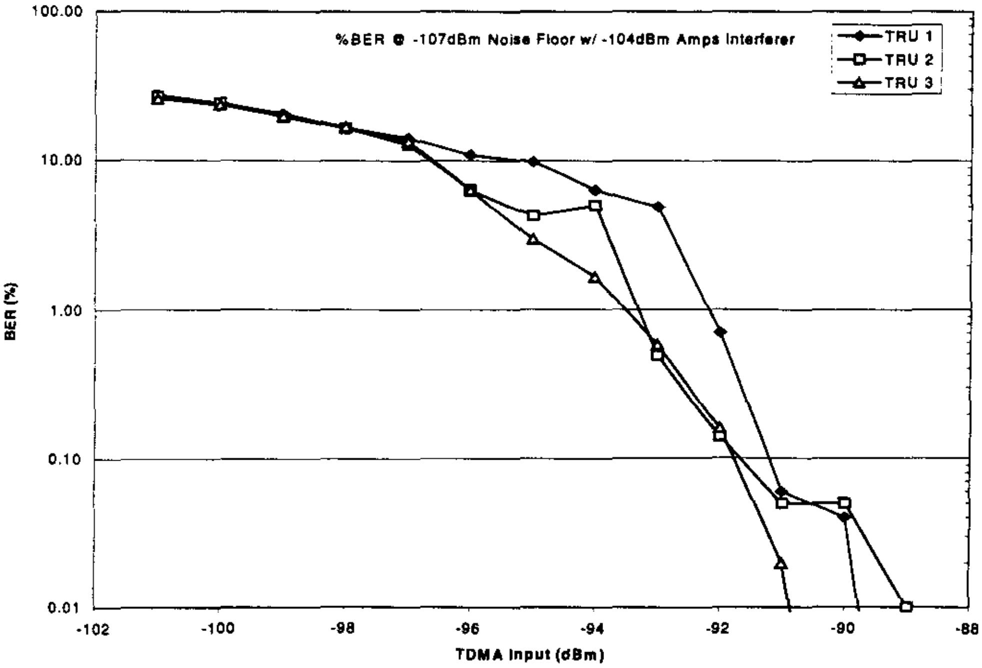


Figure 3.15 Receiver performance comparison, Urban Noise, -104 dBm AMPS interference

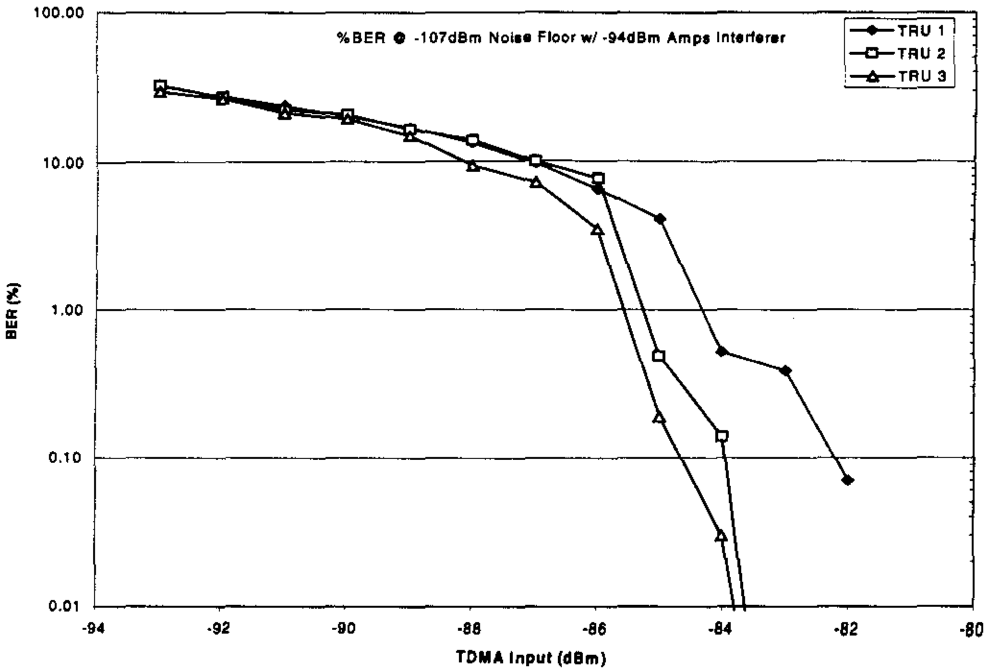


Figure 3.16 Receiver performance comparison, Urban Noise, -94 dBm AMPS interference

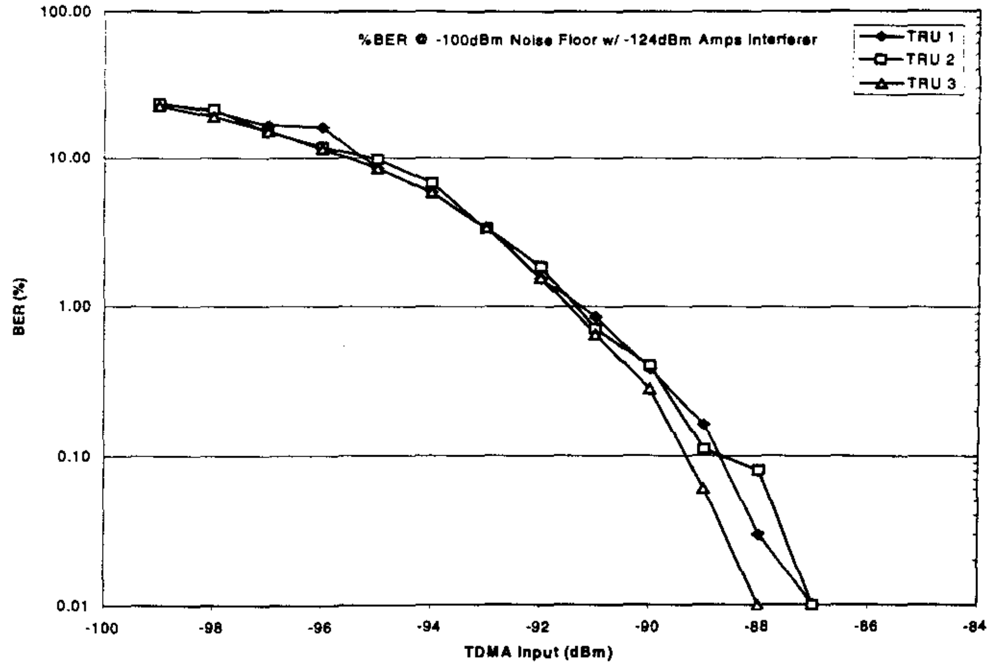


Figure 3.17 Receiver performance comparison, Dense Urban Noise, -124 dBm AMPS interference

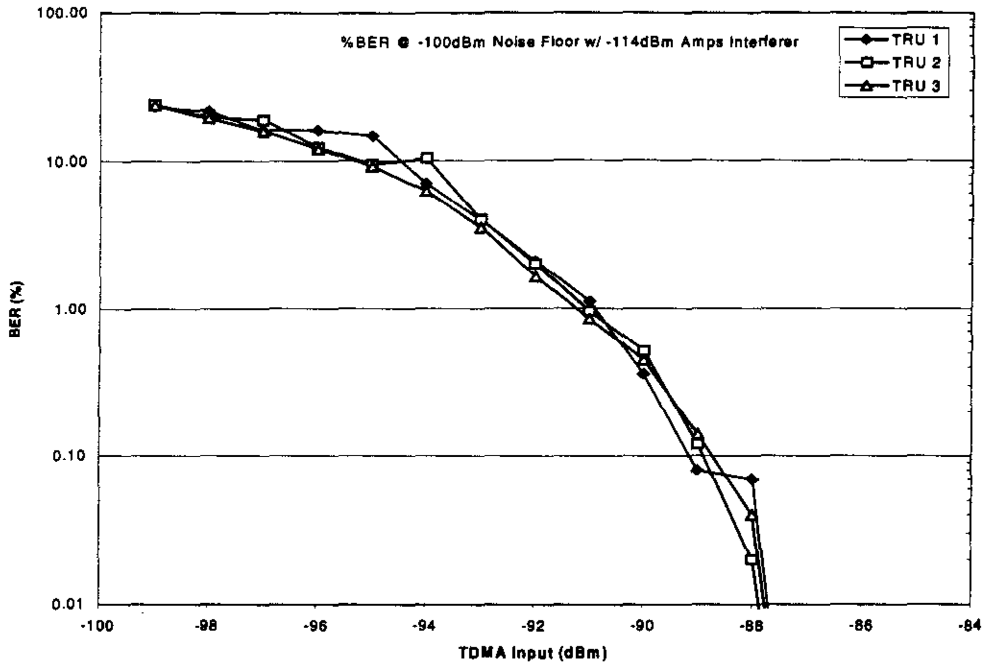


Figure 3.18 Receiver performance comparison, Dense Urban Noise, -114 dBm AMPS interference

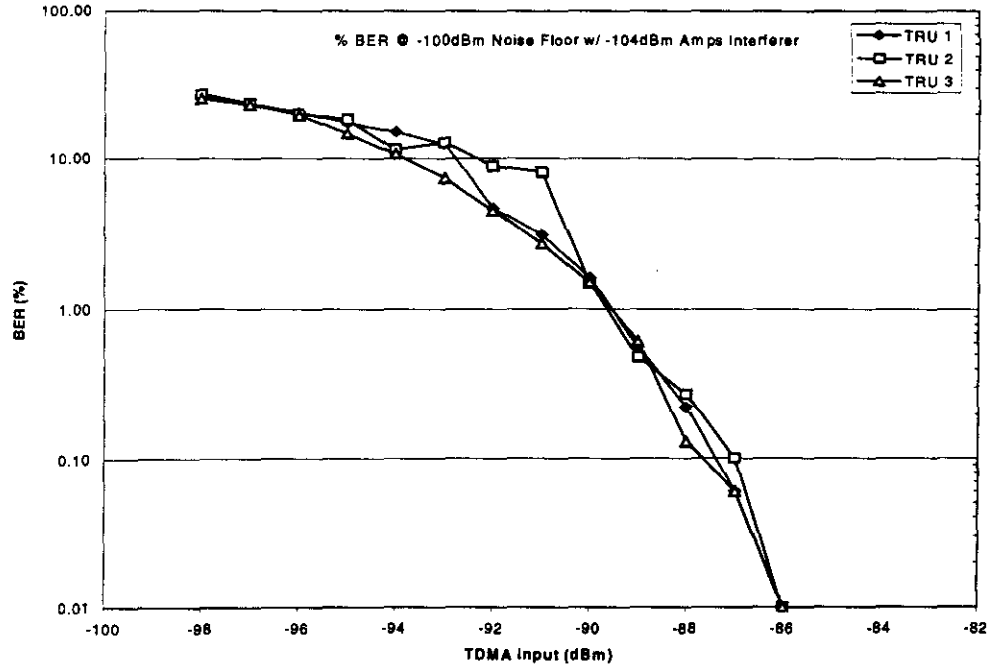


Figure 3.19 Receiver performance comparison, Dense Urban Noise, -104 dBm AMPS interference

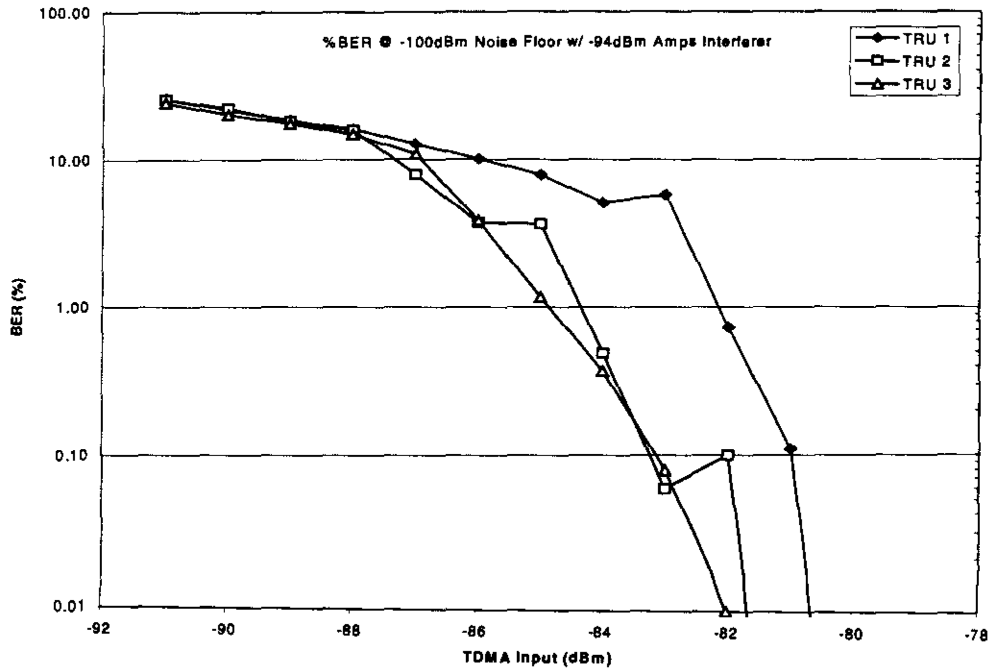


Figure 3.20 Receiver performance comparison, Dense Urban Noise, -94 dBm AMPS interference

4 RF On-Air Testing

To perform an interference evaluation, one must know the level of the TDMA signal, the level of the interference, and the performance of the receiver given signal and interference at specified levels. Having taken baseline data for cell site radio performance, and having interference level data available from the 1997 flight tests, one must obtain the remaining part of the puzzle: *What TDMA signal levels are typical for calls at a cell?* This data must be obtained off-air. The Lena site was chosen as a representative rural cell, which was convenient for testing purposes. Before making TDMA signal level measurements, it was appropriate and prudent to examine the coverage area of the cell, and verify that it was indeed performing normally. 'Normal' performance includes such things as reasonable call quality, system support functions (especially handoffs) must work, and call setup should work reliably. Only in a properly operating environment are TDMA signal level readings useful. If handoffs aren't working for instance, signal levels will be skewed downward, and calls will be 'dragged' to unusually low signal levels until quality is so poor that the calls drop.

While normal site operation was verified to ensure data quality, it should be noted that <u>no</u> attempt was made to specially optimize or 'tweak' the cell site performance. No site settings were changed for the purpose of this test.

The site was <u>not</u> intended to be perfect - it was intended to be typical of what's in the field.

4.1 Site Coverage Determination

WIZARD®, an industry accepted propagation-modeling tool that employs the Lee model for RF propagation at cellular and PCS frequencies, was used to make a preliminary determination of the RF footprint of the Lena site. A route was then laid out for a drive of the coverage area, which yielded measured data showing signal strength and handoff locations.

4.1.1 <u>Site Coverage Area Estimate</u>

United States Cellular agreed to provide their *WIZARD®* project data for the region. These data files were used to generate propagation analyses and a preliminary coverage footprint was determined. A strongest server coverage plot was generated consisting of Lena and its neighboring sites. The plot, shown in Figure 4.1, was overlaid on a street map of the Lena area, in order to visualize the road segments that Lena could reasonably be expected to cover. A representative path including both strong and weak coverage areas of the Lena site was then driven. This route attempted to match (as closely as practicable) the distribution of typical ranges and signal strengths caller traffic experiences while accessing the site. Main (paved) roads through the area and side streets in the town of Lena were emphasized. It is believed that these areas generate much of the call traffic at this site, while extremely rural unpaved roads that may see few vehicles in a day are small contributors to site traffic.

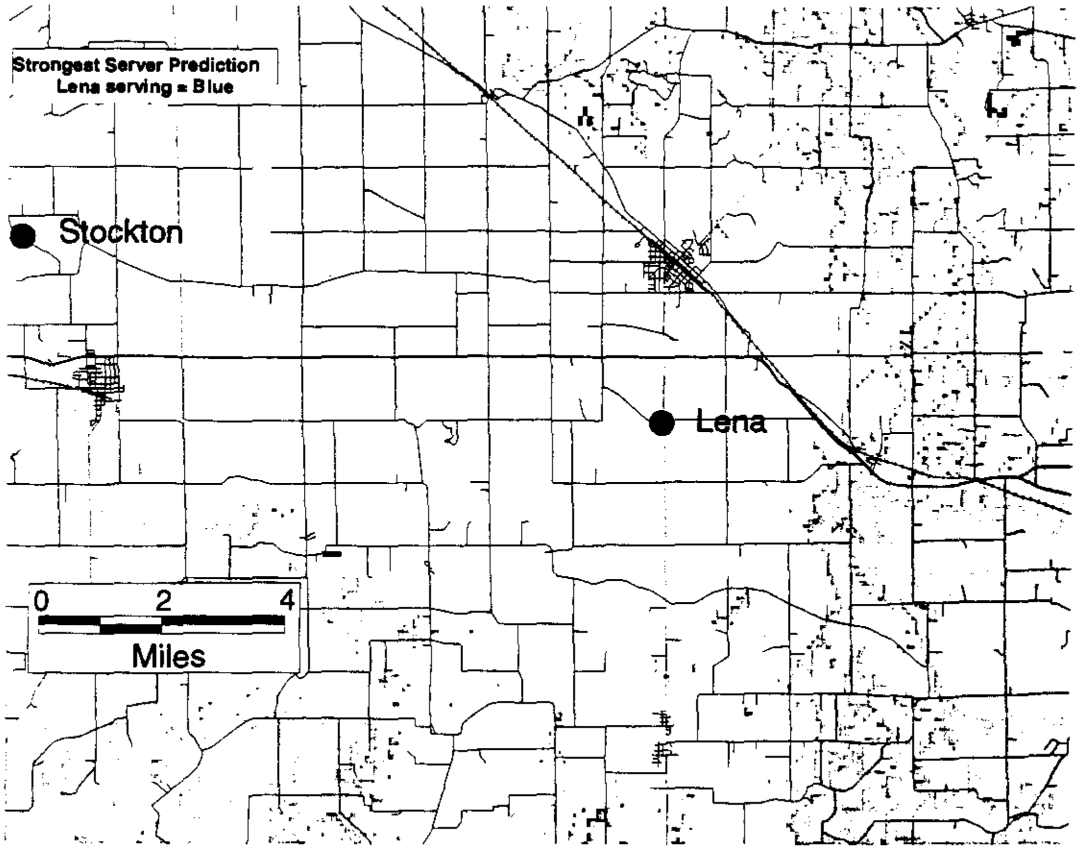


Figure 4.1 Wizard strongest-server plot showing expected coverage of Lena site.

4.1.2 Drive of the Observer Site Coverage Area

A drive of the predicted Lena cell coverage area was conducted using SAFCO Walkabout equipment, which placed and tracked IS-136 calls. Test personnel placed a call on the Lena site while well within the coverage area, and drove the periphery of the coverage area looking for handoff locations or call drops, in order to 'feel out' the actual regions normally served by Lena.

Phone activity including transmit power, RF channel and timeslot, RSSI, handoffs, etc. was recorded in a data logfile, along with GPS time and location data during the drive.
No performance/optimization changes were made to the Lena site settings for this test (except for disabling two of the three voice channel timeslots to allow spectrum analyzer logging of reverse channel data) as the site was intended to represent a typical site in its normal state, in the presence of active neighbor sites. Lena was instrumented as described in Section 4.2, and reverse channel data logging took place during the drive test. Reverse channel data was merged in postprocessing with forward channel data using GPS time as a common reference.

The drive of the coverage area of the Lena cell was conducted with a test vehicle configured according to the test setup shown in Figure 4.2.

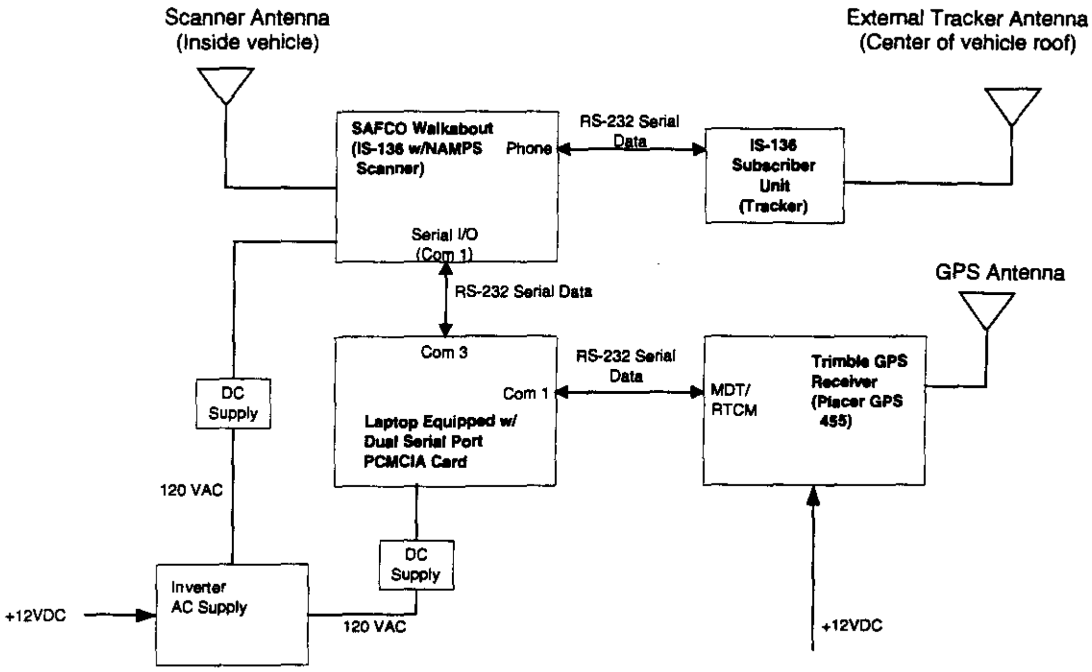


Figure 4.2 - Drive Test Vehicle Setup

Calls were initiated and data was collected along the drive route using the IS-136 subscriber unit, which was a Nokia 6160 series phone, using an external antenna. The antenna gain, less estimated cable loss was 0 dBd, ±1dB. The antenna was placed at the center of the vehicle roof. The vehicle was a typical 4-door sedan, so antenna radiation centerline was approximately 5 feet above ground.

The AMPS scanner was activated, but its antenna was inside the vehicle, so disturbances to antenna pattern and vehicle penetration loss uncertainty rendered this data essentially useless. Scanner data was not postprocessed or used. At the cell site, both Spectrum analyzers under LabView control and site receivers logged data during the drive.

The SAFCO Walkabout was configured according to the procedure in Appendix A.

4.2 On-Air Testing - Configuration

Prior to conducting the drive test discussed above, site monitoring instrumentation was installed at Lena. Both spectrum analyzers and site receivers were available to collect data, as shown in Figure 4.3 below.

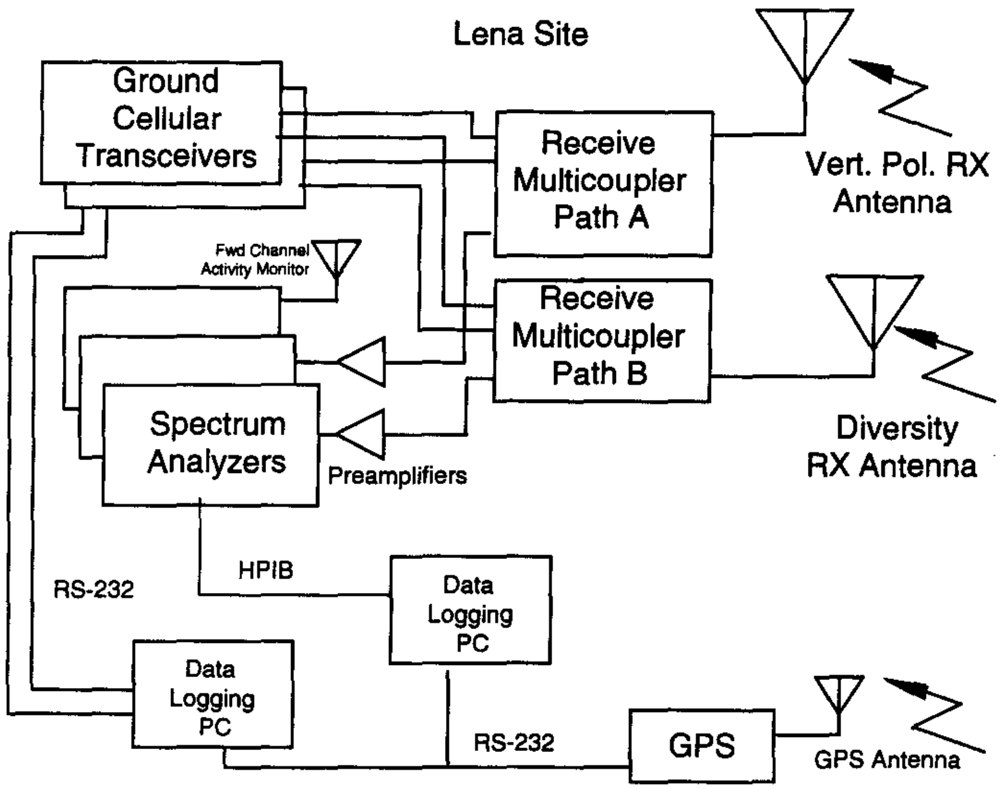


Figure 4.3 - Observer Site Instrumentation Setup

Custom software was written to poll site receivers for RSSI data, time tag and log it. This was the primary data source used. Spectrum analyzers with preamplifiers were added to the site, to measure the amplitude of reverse channel TDMA signals. The spectrum analyzers were attached to a data-logging computer, which was equipped with a GPS receiver for accurate time tagging of data. Labview software written for the July, 1997 Texas test was re-used. This software controlled the spectrum analyzers, obtained and logged the spectrum analyzer measurements through the diversity reverse channel paths, and time tagged the data with GPS time.

4.3 Site Testing – Calibration

The receive path gain was directly measured from the multicoupler input (the measurement reference point) to the actual receivers and test equipment used in making measurements. The diplexer loss (between the antenna and the diplexer input on diversity receive path 'B') was measured, so the receive path could (by calculation) also be referenced to the point at which the tower coaxial cable enters the shelter. (The Lena site has only 2 antennas, one of which is used for both transmit and receive operations.) The tower coax/jumper losses were calculated using nominal performance specifications, and antenna performance was assumed to be per manufacturer specifications.